

## RESEARCH PAPER RP1550

*Part of Journal of Research of the National Bureau of Standards, Volume 31,  
August 1943*

## THERMAL EXPANSION OF SOME INDUSTRIAL COPPER ALLOYS

By Peter Hidnert and George Dickson

## ABSTRACT

This paper gives data on the linear thermal expansion of some industrial copper-nickel, copper-nickel-aluminum, copper-nickel-tin, and miscellaneous copper alloys (copper-tin, copper-lead-antimony, copper-manganese-aluminum, copper-nickel-iron, copper-nickel-zinc, copper-nickel-tin-lead, copper-nickel-zinc-iron, copper-tin-zinc-lead, copper-zinc-aluminum-iron-manganese) for various temperature ranges between 20° and 900° C. The addition of 3 percent of nickel or the combined addition of 4.5 percent of nickel and 5 percent of aluminum to copper was found to have little effect on the linear thermal expansion. The effect of various treatments on these copper-nickel and copper-nickel-aluminum alloys was also small. The coefficients of expansion of two copper-nickel-tin alloys containing 20 and 29 percent of nickel were appreciably less than the coefficients of expansion of copper for temperature ranges between 20° and 600° C. Three copper alloys containing more than 28 percent of nickel showed the smallest coefficients of expansion of the miscellaneous alloys. The coefficients of expansion of the copper alloys reported in this paper were found to be between  $14.9 \times 10^{-6}$  and  $20.4 \times 10^{-6}$  per degree centigrade for the range from 20° to 100° C.

## CONTENTS

	Page
I. Introduction.....	77
II. Alloys investigated.....	77
III. Apparatus.....	78
IV. Results and discussion.....	78
V. References.....	82

## I. INTRODUCTION

Data obtained between 1916 and 1943 on the linear thermal expansion of some industrial copper-nickel, copper-nickel-aluminum, copper-nickel-tin, and miscellaneous copper alloys, are presented in this paper. Coefficients of expansion during the heating and cooling of the samples are given for various temperature ranges between 20° and 900° C.

## II. ALLOYS INVESTIGATED

The samples of copper alloys were obtained from the American Brass Co., Waterbury, Conn., American Manganese Bronze Co., Holmesburg, Philadelphia, Pa., Aterite Co., Inc., New York, N. Y., Bunting Brass & Bronze Co., Toledo, Ohio, Crane Co., Chicago, Ill., Curtis Bay Copper & Iron Works, South Baltimore, Md., National Bureau of Standards, Scovill Mfg. Co., Waterbury, Conn., Stewart Mfg. Corp., Chicago, Ill., and the U. S. Shipping Board. The length of each sample used in the determinations of linear thermal

expansion was 300 mm (11.8 in.). The cross sections of the samples, their treatments, and chemical compositions are given in table 1. Most of the values for chemical composition were furnished by the manufacturers.

### III. APPARATUS

The types of precision micrometric thermal-expansion apparatus described by Souder and Hidnert [1]<sup>1</sup> were used for the determinations of the linear thermal expansion of the copper alloys.

### IV. RESULTS AND DISCUSSION

Expansion curves on heating and on cooling were plotted from the observations made on the samples of copper-nickel, copper-nickel-aluminum, copper-nickel-tin, and miscellaneous copper alloys at various temperatures between 20° and 900° C. Coefficients of expansion and coefficients of contraction were obtained from these curves and are given in table 1. This table also shows, for most of the samples, the permanent changes in length that occurred as a result of the heating and cooling in the thermal-expansion tests.

The data on samples 1493 and 1493(a), and samples 1494 and 1494(a) indicate that the coefficients of expansion on a second heating are nearly the same as the coefficients of contraction during the previous cooling. From these data and previous experience it is believed that similar results will be obtained for most of the other copper alloys on a second heating. The coefficients obtained during the first cooling from the maximum temperature to 20° C may therefore be used for repeated heating and cooling through this temperature range. However, if an alloy is repeatedly heated to only a moderate temperature, the coefficients of expansion during the first heating should be used.

Most of the coefficients of expansion of the samples of copper-nickel alloys and copper-nickel-aluminum alloys are in close agreement with the coefficients of expansion<sup>2</sup> of copper reported by Hidnert [5] and Esser and Eusterbrock [6]. The average deviation of the coefficients of expansion from the corresponding coefficients of expansion of copper is  $\pm 0.2 \times 10^{-6}$ . These results indicate that the addition of 3 percent of nickel or the combined addition of 4.5 percent of nickel and 5 percent of aluminum to copper has little effect on the linear thermal expansion between 20° and 800° C. The linear thermal expansion is affected only slightly by the treatments of the copper-nickel and copper-nickel-aluminum alloys, even though the mechanical properties of these alloys differed significantly.

Johansson [7], Krupkowski [8], and Aoyama and Ito [9] determined coefficients of linear thermal expansion of copper-nickel alloys for several temperature ranges between -253° and +444° C. They found that the addition of nickel lowered the coefficients of expansion. For the range 18° to 444° C., Krupkowski [8] reported that the coefficient of expansion decreased slowly from  $18.1 \times 10^{-6}$  per degree centigrade for 0 percent of nickel to  $15.1 \times 10^{-6}$  per degree centigrade for 100-percent nickel. This corresponds to an average decrease of  $0.03 \times 10^{-6}$  in the coefficient of expansion of copper-nickel alloys for a change of 1 percent of nickel for the temperature range indicated.

<sup>1</sup> Figures in brackets indicate the literature references at the end of this paper.

<sup>2</sup> Given for reference, in last line of table 1.

TABLE 1.—Coefficients of linear expansion of some industrial copper alloys

Sample	Commercial name	Chemical composition									Treatment	Average coefficients of expansion <sup>a</sup> per degree centigrade										Change in length after heating and cooling <sup>b</sup>
		Cu	Ni	Al	Sn	Zn	Fe	Mn	Pb	Si		20° to 100° C	20° to 200° C	20° to 300° C	20° to 400° C	20° to 500° C	20° to 600° C	20° to 700° C	20° to 800° C	20° to 900° C		
A. COPPER-NICKEL ALLOYS																						
1489-----	Tempaloy 836-----	% 96.06	% 3.02	% -----	% -----	% -----	% 0.12	% -----	% -----	% 0.61	Cast at 1,200° C. and machined to 3⁄8 inch in diameter.	×10 <sup>-6</sup> 16.6 *17.0	×10 <sup>-6</sup> 17.1 *17.3	×10 <sup>-6</sup> 17.5 *17.7	×10 <sup>-6</sup> 17.8 *17.9	×10 <sup>-6</sup> 18.2 -----	×10 <sup>-6</sup> 18.7 -----	×10 <sup>-6</sup> 19.2 *19.0	×10 <sup>-6</sup> 19.5 *19.4	×10 <sup>-6</sup> -----	% -----	} +0.01
1490-----	do-----	96.06	3.02	-----	-----	-----	.12	-----	-----	.61		Cast at 1,200° C. annealed at 850° C for 3 hours, quenched in water, heat treated at 450° C for 3 hours, cooled slowly in air, and machined to 3⁄8 inch in diameter.	15.6 *17.2	16.5 *17.2	17.1 *17.6	17.6 *17.9	18.0 -----	18.6 -----	19.3 *18.9	19.4 *19.1	-----	
1396-----	do-----	96.00	3.14	-----	-----	-----	-----	-----	-----	.86	5⁄16 inch diameter rod annealed at 850° C and quenched.		16.6 -----	16.7 -----	17.2 -----	17.3 -----	17.8 -----	18.2 -----	18.9 -----	19.3 -----	-----	% -----
1395-----	do-----	95.71	3.22	-----	-----	-----	-----	-----	-----	.69		Drawn from 3⁄8 to 5⁄16 inch in diameter.	16.9 -----	17.0 *17.1	17.7 *17.5	18.0 *17.8	18.3 -----	18.7 *18.3	19.1 *18.6	19.9 *18.7	-----	% -----

See footnotes at end of table.

TABLE 1.—Coefficients of linear expansion of some industrial copper alloys—Continued

Sample	Commercial name	Chemical composition									Treatment	Average coefficients of expansion <sup>a</sup> per degree centigrade										Change in length after heating and cooling <sup>b</sup>
		Cu	Ni	Al	Sn	Zn	Fe	Mn	Pb	Si		20° to 100° C	20° to 200° C	20° to 300° C	20° to 400° C	20° to 500° C	20° to 600° C	20° to 700° C	20° to 800° C	20° to 900° C		
B. COPPER-NICKEL-ALUMINUM ALLOYS																						
1491-----	Tempaloy 841-----	89.67	4.47	5.04	%	%	%	%	%	0.82	Cast at 1,200° C, and machined to 3/8 inch in diameter.	×10 <sup>-6</sup> 16.4 *16.8	×10 <sup>-6</sup> 16.8 17.0	×10 <sup>-6</sup> 17.4 *18.0	×10 <sup>-6</sup> 17.8 -----	×10 <sup>-6</sup> 18.3 -----	×10 <sup>-6</sup> 18.8 -----	×10 <sup>-6</sup> 19.1 *19.2	×10 <sup>-6</sup> 19.5 *19.6	×10 <sup>-6</sup> -----	%	
1492-----	do-----	89.67	4.47	5.04	-----	-----	-----	-----	-----	.82	Same treatment as sample 1490.	16.7 *16.8	*17.1 *17.6	17.5 *17.9	18.1 -----	18.6 -----	19.5 -----	19.2 *19.0	19.1 *19.4	-----	-.02	
1493-----	do-----	89.67	4.47	5.04	-----	-----	-----	-----	-----	.82	Hot rolled at 750° C from 1½ to ¾ inch in diameter, annealed at 800° C, quenched in water, drawn to ¾ inch in diameter, annealed, drawn to ½ inch in diameter, annealed, drawn to ¾ inch in diameter, annealed at 850° C for 3 hours and quenched.	17.0 *16.6	16.8 *17.1	17.2 *17.5	17.8 *17.9	18.3 *18.2	19.0 -----	19.5 *18.7	-----	-----	+ .05	
1493 (a)-----	do-----	89.67	4.47	5.04	-----	-----	-----	-----	-----	.82	Same treatment as sample 1493, then heated to 700° C and slowly cooled.	16.8 *16.5	17.0 *17.0	17.4 *17.9	17.9 -----	18.3 -----	18.5 -----	18.7 -----	19.1 *19.4	-----	-.03	
1494-----	do-----	89.67	4.47	5.04	-----	-----	-----	-----	-----	.82	Same treatment as sample 1493, then heat treated at 450° C for 3 hours and slowly cooled in air.	16.8 *16.6	17.0 *17.0	17.4 *17.5	17.9 *17.9	18.3 -----	19.1 -----	19.7 *19.0	19.8 *19.4	-----	+ .03	
1494 (a)-----	do-----	89.67	4.47	5.04	-----	-----	-----	-----	-----	.82	Same treatment as sample 1494, then heated to 800° C and slowly cooled.	16.6 *16.4	16.9 *17.1	17.3 *17.5	17.9 *17.9	18.2 -----	18.7 -----	19.0 *19.1	19.3 *19.5	-----	-.01	
C. COPPER-NICKEL-TIN ALLOYS																						
1187-----	Adnic (admiralty nickel).	69.57	28.70	---	0.91	---	---	---	---	---	Rod 1 3/16 inches in diameter, extruded from 1 3/8 inches in diameter and finished hard, with a 1/16-inch draught after annealing.	*15.2	*15.4	*16.3	-----	-----	-----	-----	-----	-----	+0.00	
1085-----	-----	68	20	---	12	---	---	---	---	---	Bar 1/4-by 1/4-inch cross section, cast.	-----	16.2	-----	16.9	-----	18.1	-----	-----	22.9	-----	

## D. MISCELLANEOUS COPPER ALLOYS

1445	Red brass	84.96			5.02	5.15			4.87	Cast rod	<sup>d</sup> 17.8 <sup>i</sup> 17.7	<sup>d</sup> 18.1 <sup>i</sup> 18.0	<sup>d</sup> 18.5 <sup>i</sup> 18.2	<sup>d</sup> 18.9 <sup>i</sup> 18.6	<sup>d</sup> 19.3	<sup>d</sup> 20.0 <sup>i</sup> 19.4	<sup>d</sup> 20.6 <sup>i</sup> 19.8				+0.05
1575		84.93		5.5			0.22	9.4		Cold-drawn wire 1 mm in diameter, baked in air at 140° C for 18 hours.	<sup>i</sup> 18.1 <sup>i</sup> 17.4									+0.01	
1444A	Bronze	84.84			14.95				0.21	Outside section (cross section, circular segment with $\frac{5}{32}$ -inch rise) of $\frac{7}{8}$ inch diameter, cast rod.	<sup>d</sup> 18.0 <sup>i</sup> 17.7	<sup>d</sup> 18.2 <sup>i</sup> 18.2	<sup>d</sup> 18.6 <sup>i</sup> 18.7	<sup>d</sup> 18.8 <sup>i</sup> 19.1	<sup>d</sup> 19.3 <sup>i</sup> 19.6	<sup>d</sup> 19.8 <sup>i</sup> 20.0				-0.02	
1084		71	18		6	1			4	Bar $\frac{1}{4}$ -by $\frac{1}{4}$ -inch cross section, cast.		16.4		17.0		18.5		24.6			
1073	Manganese bronze	66.2	( <sup>f</sup> )	4.8	( <sup>f</sup> )	<sup>a</sup> 22.9	2.6	3.5	( <sup>f</sup> )	Rod $\frac{3}{8}$ inch in diameter, machined from $\frac{1}{8}$ inch diameter casting.	18.7	19.8	20.8						-0.00		
897 <sup>b</sup>	Hytsen bronze	63-68		3-6	<sup>i</sup> 0.50	( <sup>i</sup> )	2-4	2.5-5	<sup>i</sup> 0.20	Extruded rod, $\frac{3}{8}$ inch diameter.	<sup>i</sup> 18.5 <sup>i</sup> 20.4	<sup>i</sup> 17.0 <sup>i</sup> 20.6	<sup>i</sup> 17.0 <sup>i</sup> 21.5						-0.13		
897 (a) <sup>h</sup>	do	63-68		3-6	<sup>i</sup> 1.50	( <sup>i</sup> )	2.4	2.5-5	<sup>i</sup> 1.20	Same treatment as sample 897, then heated to 300° C and cooled, and aged at room temperature for 21 years.	<sup>i</sup> 19.0 <sup>i</sup> 19.0	<sup>i</sup> 20.6 <sup>i</sup> 20.3	<sup>i</sup> 21.3 <sup>i</sup> 21.3						-0.00		
683	Wrought Aterite	65	11			22	1.5	0.5		Cold-rolled and cold-drawn rod, $\frac{1}{2}$ inch in diameter.	<sup>i</sup> 16.5	<sup>i</sup> 17.0	<sup>i</sup> 17.4				19.1	19.7			
1026	Everbrite	64.9	28.5				4.9	.9		Bar $\frac{1}{2}$ by $\frac{7}{16}$ -inch cross section, cast.			15.8	16.2			18.0		+0.01		
934 <sup>i</sup>	Stewart bearing metal.	64							34	Rod $\frac{3}{8}$ inch in diameter, machined from sand casting.	<sup>i</sup> 20.1	<sup>i</sup> 20.0	20.0	<sup>i</sup> 19.9	<sup>i</sup> 19.8						
280	Aterite	63.60	13.18			<sup>a</sup> 21.45	1.72		0.05	Rod $\frac{1}{2}$ inch in diameter, treatment not known.	<sup>i</sup> 17.2 <sup>i</sup> 17.2 <sup>i</sup> 17.4	<sup>i</sup> 17.5 <sup>i</sup> 17.6 <sup>i</sup> 17.8	<sup>i</sup> 18.0 <sup>i</sup> 18.1						-0.00		
281 <sup>m</sup>	do										<sup>i</sup> 17.2 <sup>i</sup> 17.4	<sup>i</sup> 17.6 <sup>i</sup> 17.8							-0.00		
498	Nickel silver	58.4	15.7		( <sup>f</sup> )	<sup>a</sup> 25.5	0.22	.15	( <sup>f</sup> )	Tube $\frac{3}{16}$ -inch outside diameter.	<sup>i</sup> 17.4		17.8	18.3	18.9				-0.04		
682	Aterite No. 9	55	32			7	6			Bar $\frac{1}{2}$ -by $\frac{1}{2}$ -inch cross section, cast.	<sup>i</sup> 14.9	<sup>i</sup> 15.4	<sup>i</sup> 16.0	<sup>i</sup> 19.1	<sup>i</sup> 19.7		18.3	18.6	19.2		
621 <sup>o</sup>	Aterite No. 4	48.80	31.26			8.93	8.83	0.16	2.23 0.66	Bar $\frac{3}{8}$ -by $\frac{3}{8}$ -inch cross section, cast.		15.4	16.1	16.6	17.1	17.6	18.2	18.9			
	Copper [5, 6] <sup>p</sup>	100									16.8	17.3	17.7	17.9	18.3	18.6	19.0	19.4	19.8		

<sup>a</sup>The values indicated by asterisks were determined from the curves on cooling the samples from the maximum temperature to 20° C.

<sup>b</sup>Determined from the expansion curve on heating and the contraction curve (or final observation) on cooling. The plus sign indicates an increase in length and the minus sign a decrease in length.

<sup>c</sup>Reported by Hidnert and Sweeney [2] to the American Physical Society.

<sup>d</sup>Reported by Hidnert [3] to the American Physical Society.

<sup>e</sup>Reported on page 159 of publication by Thomas [4].

<sup>f</sup>Not detected.

<sup>g</sup>By difference.

<sup>h</sup>Chemical composition within range specified by Federal Specification QQB721a, Class B, or Navy Specification 46B15, Class B.

<sup>i</sup>Maximum.

<sup>j</sup>Remainder.

<sup>k</sup>Computed from a second-degree equation derived from the observations.

<sup>l</sup>Antimony 2 percent. After heating the sample to 500° C and cooling to 20° C incident to the thermal-expansion determinations, several small globules (probably lead) were found on the surface of the sample.

<sup>m</sup>Duplicate of sample 280.

<sup>n</sup>Heating coil of oil bath burned out before observation could be taken at 300° C.

<sup>o</sup>Carbon 0.41 percent. (Apparent total contents of elements 101.3 percent.)

<sup>p</sup>Added for comparison with the copper alloys.



The coefficients of expansion of the copper-nickel alloys of the present investigation are in good agreement with comparable coefficients of expansion obtained by these observers.

The coefficients of expansion of the two copper-nickel-tin alloys containing 20 and 29 percent of nickel are appreciably less than the coefficients of expansion of copper for temperature ranges between 20° and 600° C. For the range 20° to 900° C the coefficient of expansion of the copper-nickel-tin alloy containing 20 percent of nickel is about 16 percent higher than the coefficient of expansion of copper.

The substitution of 5 percent of zinc and 5 percent of lead for 10 percent of tin in the bronze containing 15 percent of tin caused slight changes in the coefficients of expansion. The three miscellaneous alloys (samples 1026, 682, and 621) containing more than 28 percent of nickel show the smallest coefficients of expansion of this group in table 1. The coefficients of expansion (or contraction) of samples 1073, 897, 897(a), and 934, which do not contain nickel, are the largest of the alloys investigated. The coefficients of the latter four samples exceed the coefficients of expansion of copper, and the coefficients of expansion of the former three alloys are less than the coefficients of expansion of copper. The coefficients of expansion of samples 683, 280, and 281 are larger than the corresponding coefficients of expansion reported by Cook [10] for annealed copper-nickel-zinc alloys.

Data on the linear thermal expansion of other copper alloys investigated at the National Bureau of Standards have been published in previous papers [5, 11, 12, 13, 14].

## V. REFERENCES

- [1] W. Souder and P. Hidnert, *Measurements on the thermal expansion of fused silica*, BS Sci. Pap. **21**, 1 (1926-27) S524.
- [2] P. Hidnert and W. T. Sweeney, *Thermal expansion of copper-nickel-tin alloy*, Phys. Rev. **35**, 667 (1930).
- [3] P. Hidnert, *Thermal expansion of copper alloys*, Phys. Rev. **39**, 551 (1932).
- [4] J. L. Thomas, *Electrical-resistance alloys of copper, manganese, and aluminum*, J. Research NBS **16**, 149 (1936) RP863.
- [5] P. Hidnert, *Thermal expansion of copper and some of its important industrial alloys*, Sci. Pap. BS **17**, 91 (1922) S410. (This paper contains data on copper-zinc alloys, copper-tin alloys and aluminum bronze.)
- [6] H. Esser and H. Eusterbrock, *Untersuchung der Wärmeausdehnung von einigen Metallen und Legierungen mit einem verbesserten Dilatometer*, Archiv Eisenhüttenwesen **14**, 341 (1941).
- [7] C. H. Johansson, *Die thermische Ausdehnung einiger binären Mischkristalle*, Ann. Physik **76**, 445 (1925).
- [8] A. Krupkowski, *Études des alliages nickel-cuivre*, Rev. Mét. (Mémoires) **26**, 131, 193 (1929).
- [9] S. Aoyama and T. Ito, *Thermal expansion of nickel-copper alloys at low temperatures*, Tôhoku Imp. Univ. Sci. Rep. **27**, 348 (1939).
- [10] M. Cook, *The physical properties and annealing characteristics of standard nickel silver alloys*, J. Inst. Metals **58**, 151 (1936).
- [11] P. D. Merica and L. W. Schad, *Thermal expansion of alpha and of beta brass between 0° and 600° C, in relation to the mechanical properties of heterogeneous brasses of the Muntz metal type*, Bul. BS **14**, 571 (No. 4, 1919) S321.
- [12] P. Hidnert, *Thermal expansion of bearing bronzes*, BS J. Research **12**, 391 (1934) RP665.
- [13] P. Hidnert, *Thermal expansion of copper-beryllium alloys*, J. Research NBS **16**, 529 (1936) RP890.
- [14] P. Hidnert, *Thermal expansion of some bronzes*, J. Research NBS **30**, 75 (1943) RP1518.

WASHINGTON, May 25, 1943.